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Approach for Total Productive Maintenance Evaluation in Water Productivity: A Case Study at Mahasawat Water Treatment Plant

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Abstract

Nowadays, many water treatment plants face the problems of equipment breakdown and water loss during water production process. A method to solve these problems is to implement Eight pillars strategy (EPS), one of Total Productive Maintenance (TPM) strategy to reduce equipment breakdown, decrease water loss and enhance equipment effectiveness. Failure rate (FR), availability (A), performance efficiency (PE), quality rate (QR) were determined by evaluating equipment effectiveness through Overall Equipment Effectiveness (OEE).They were also evaluated to find the entire equipment/plant effectiveness through Net Equipment Effectiveness (NEE). In this study, the chlorinator machines in each couple phase 1&2 and 3&4 at Mahasawat Water Treatment Plant (MHS) were considered as a case study for practicing EPS. The reduction of FR and increase of A, PE and QR were revealed after practicing EPS to chlorinators as evidently evaluated in this paper. They affect to higher OEE and NEE in all couple phases. As a consequence, the chlorinators were able to operate continuously for longer time with high efficiency. The plant can also produce higher quantity of qualified water to customers by monitoring the final water treatment process via Profit Cost (PC). The proposed 17 steps for OEE, NEE and PC evaluations are shown in this paper might be a good approach for other water treatment plant to get higher chlorinator effectiveness and lower water loss.

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Keywords: NEE, OEE, Profit cost, TPM, water loss

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1. Introduction

Metropolitan Waterworks Authority (MWA), Thailand, has been responsible to produce and supply quality water to its industrial, residential and bureaucratic customers in Bangkok, Nonthaburi and Samutprakarn provinces. Mahasawat Water Treatment Plant (MHS) is the one of MWA's plants to produce, transmit and distribute quality water to customers in western part of its areas with total maximum capacity of production about 2,000,000 sq.m. per day, 800,000 sq.m. for couple phase 1&2, and 1,200,000 sq.m. for couple phase 3&4 [1]. Currently, MHS encounters equipment breakdown frequently, equipment outreaching-efficiency and loss water about 6-7 percentage per day from water treatment process. They result in losses in transmitting and distributing quality water to customers occasionally.

In water production process at MHS, chlorine is the most significant substance for conserving quality of water according to World Health Organization standard (WHO), to be dosed into raw water by chlorinator. However, when a chlorinator needs repairing at once, MHS losses budget from transmitting and distributing quality water to customer due to draining unqualified water.

To eliminate these problems above [2,3], Eight pillars strategy (EPS), one of Total Productive Maintenance (TPM) strategies, is the metrical approach established by The Japan Institute of Plant Maintenance (JIPM) in 1971. EPS gives concept of zero product defects, zero breakdowns and minimal losses and better operation and maintenance managements for the plant to practice with the principle of 5S, Autonomous maintenance, Kaizen, Planned maintenance, Quality maintenance, Training, Office TPM, and safety Health and Environment according to its objective. EPS also aims to increase availability and effectiveness of existing equipment in a given situation in many production companies[4], through the effort of minimizing input (improving and maintaining equipment at optimal level to reduce its life cycle cost) and the investment in human resources which results in better hardware utilization and, operation and maintenance managements [5,6]. These concepts are applied to reduce water loss from water production process, decrease chlorinator's failure rate, increase chlorinator effectiveness and enhance skills to operators to fundamentally handle with damaged chlorinator in each couple phase at MHS. Subsequently, in evaluating the result from practicing EPS to chlorinator, Overall Equipment Effectiveness (OEE) and Net Equipment Effectiveness (NEE) are evaluated for chlorinator effectiveness and net entire plant effectiveness, respectively. Also, Profit Cost (PC) is indexed to find budget that MHS will get from transmitting and distributing quality water to customers increasingly after practicing EPS [7].

There are 6 sections discussed in this paper. Introduction of this study is reviewed in section 1. Total Productive Maintenance (TPM) is detailed in section 2. Failure rate, OEE, NEE and Profit Cost are determined in calculation methodology in section 3. Parameters for evaluation are shown in section 4. 17 steps for OEE, NEE and PC evaluations and their results before and after practicing EPS are shown in evaluation approach and result in section 5, and conclusion of this study is discussed in section 6.

2. Total Productive Maintenance

To probe any problem occurring to equipment such as breakdown efficiently, Nagajima, a major contributor of Total Productive Maintenance (TPM), set TPM as an approach to maximize equipment effectiveness to system. Nagajima also purposes the systematic approach to practice and implement called Eight pillars strategy (EPS). It strives to take concept of zero production defects and applying it to equipment to have zero breakdowns and minimal production losses [9,10]. EPS also texts the theory operation and maintenance officers to follow for getting maximize equipment effectiveness and advanced knowledge skills to handle with problem efficiently. According to Nagajima's text [11,12], the goal of TPM by EPS motivates officers to achieve 85 percentage of equipment effectiveness to be world class and a benchmark for a typical manufacturing capacity. TPM can be illustrated in Fig. 1and EPS can be described in Table 1 [13,14].

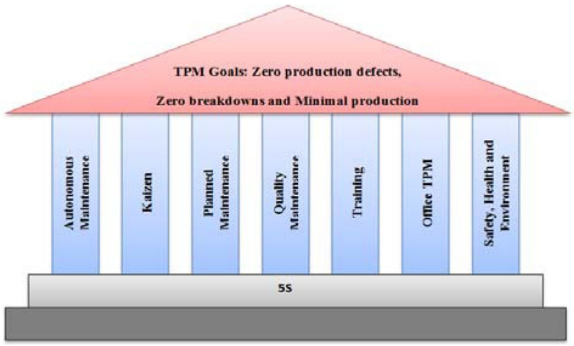

Fig. 1 Eight pillars of TPM

Table 1. Description of Eight pillars strategy

No.	Pillar	Description
1.	5S	5S comprise Seiri, Seiton, Seiso, Seiketsu and Shitsuke helps officer to manage surrounding work place to be clearly seen by people or equipment to be disciplined.
2.	Autonomous maintenance	Operator is able to take care of small reparation on failed equipment by without maintenance officer. Maintenance officer can spend time learning and practicing other advanced skills to maintain equipment.
3.	Kaizen	"Kai" means change and "Zen" mean good for better. The principle of this is "a very large number of small improvements are move effective in an organizational environment than a few improvments of large value". Kaizen involve all people in organization to perform to reduce losses and increase efficiency not only for administrator but also equipment.
4.	Planned maintenance	The method and activity to prevent equipment breakedown aim for continuously producing quality goods comprise Preventive maintenance (PM), Brakedown maintenance (BM), Corrective maintenance (CM) and Maintenace prevention (MP).
5.	Quality Maintenance	It is aimed for maintaining equipment to be perfectly ready to operate and produce quality goods without breakdown by quality goods is anticipated to be main variable.
6.	Training	Training intends to moralize officers to perform all required functions of equipment. Especially operators are trained to handle with failed and damaged equipment with not only "Know-How" but have to gain "Know-Why" to acheive root of any problem and they can teach others how to overcome it as well.
7.	Officer TPM	To improve productivity and efficiency in the administrative roles, it aims to establish work procedure for officers to follow to eliminate any breakdown causes.
8.	Safety, Health and Environment (SHE)	SHE is focused on the promote and activity to predict and prevent any damage from work in surrounding area and work place to officers to recognize Zero accident, Zero health damage and Zero fires compaigns

3. Calculation methodology

3.1 Failure rate

Failure rate indicates the frequency of considered equipment fails per unit at observed time. In this study, chlorinators are deemed to find their failure rate. Valve, rota meter and regulator are the tools connectedly grouped as series form in a chlorinator. Nevertheless, when a tool in a chlorinator fails, chlorinator cannot normally operate and it is then numbered to be a time of failure rate of chlorinator. Chlorinators in each couple phase at MHS are arranged as parallel form shown in Fig.2. Total of failure rate of chlorinators can be defined by equation 1[15].

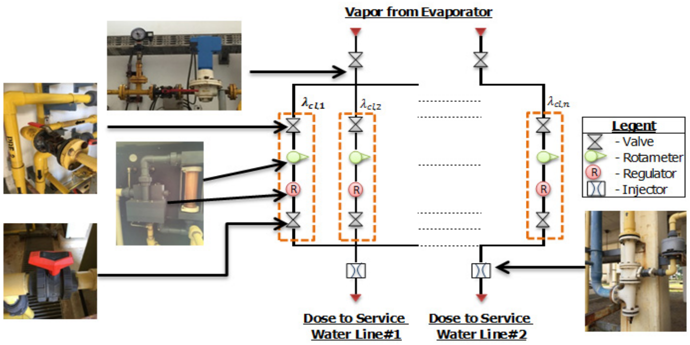

Fig.2 Failure rate of chlorinator

$$\lambda_{cl,eq} = \frac{1}{(\frac{1}{\lambda_{cl,1}}+\frac{1}{\lambda_{cl,2}}+..+\frac{1}{\lambda_{cl,n}})} \tag{1}$$

Where, $\lambda_{cl,eq}$ is total number of failure rate of chlorinators
$\lambda_{cl,n}$ is failure rate of chlorinator n.

3.2 Overall Equipment Effectiveness

Overall Equipment Effectiveness (OEE) is the popular index for many plants to measure their equipment efficiency operating in production process. It is indicated as the core quantitative metric of TPM to express both the performance and reliability of production process, efficiency (doing things right) and effectiveness (doing the right things) of equipment [16,17,18]. Nagajima [14] describes six big equipment losses in general equipment and plant as follows:

1. Equipment failure/breakdown losses are categorized as time losses when productivity is reduced, and quality losses caused by defective products,
2. Set-up/adjustment time losses result from downtime and defective products that occur when production of one item ends and the equipment is adjusted to meet the requirements of another item,
3. Idling and minor stop losses occur when the production is interrupted by a temporary malfunction or when a machine is idling,
4. Reduced speed losses refer to the difference between equipment design speed and actual operating speed,
5. Reduced yield occurs during the early stage of production from machine start up stabilization,
6. Quality defects and rework are losses in quality caused by malfunctioning production equipment.

In this study, time, speed and availability of chlorinators in 1 year (525,600 minutes) are considered for OEE evaluation. Related time for OEE evaluation is shown as time model in Fig.3 and explained as following:

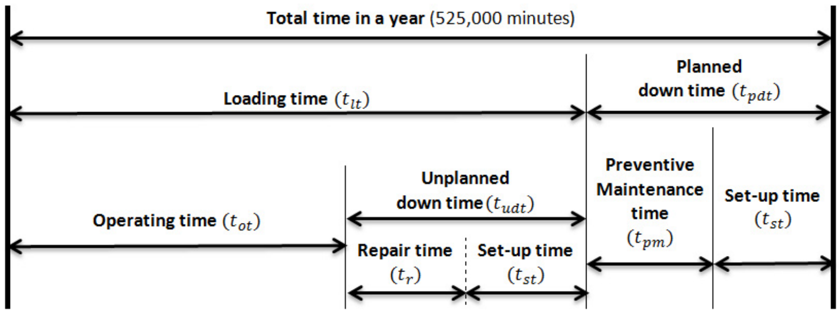

Fig.3 Time model for OEE evaluation

- "Loading time" (t_{lt}) – period of time that officer expects chlorinator to operate.
- "Planned down time" (t_{pdt}) - period of time that officer intentionally stops operating chlorinators. It consists of
  "Preventive Maintenance (PM)" time (t_{pm}) - period of time for scheduled PM plan
  "Set-up" time (t_{st}) - period of time that chlorinator must use in starting-up.
- "Operating time" (t_{ot}) – period of actual time that chlorinator operates.
- "Unplanned down time" (t_{udt}) – period of time that chlorinator does not operate in breakdown status. Officers must take
  "Repair time" (t_r) – period of time that chlorinator is repaired. And add t_{st}

In accordance with above, 3 factors of OEE are considered to evaluate chlorinator effectiveness as follows:

3.2.1 Availability (A)

Availability is defined as total available time of a chlorinator to dose chlorine into raw water. Failure rate, loading time, operating time, planned down time, unplanned down time, preventive maintenance time, repair time and set-up time of a chlorinator in a year are considered to find out the result. Thus, Availability (A) can be defined by equation 2.

$$A = \frac{t_{ot}}{t_{lt}} \times 100\% \quad (2)$$

Where,

$$t_{ot} = t_{lt} - t_{udt} \quad (3)$$

$$t_{lt} = 525600 - (t_{pm} + t_{st}) \quad (4)$$

$$t_{udt} = \lambda_{cl,eq} \times (t_r + t_{st}) \quad (5)$$

$$t_{pdt} = t_{pm} + (\lambda_{cl,eq} \times t_{st}) \quad (6)$$

3.2.2 Performance Efficiency (PE)

Performance Efficiency is defined as the design cycle time, which means the theoretical time when chlorine is dosed into raw water at designed speed of a chlorinator. Performance Efficiency (PE) can be defined by equation 7.

$$PE = \frac{t_{ict} \times N_{rw}(sec) \times 100\%}{t_{ot}} \quad (7)$$

Where, N_{rw} is quantity of raw water,

t_{ict} is ideal cycle time at designed dosing speed, it can be calculated from equation 8.

$$t_{ict} = \frac{t_{ot}}{N_c} \quad (8)$$

Where, N_c is the quantity of chlorine dosed into raw water at designed speed, it can be calculated from equation 9.

$$N_c = N_{ac} \times v_{mds}(hr) \quad (9)$$

Where, $v_{mds}(hr)$ is velocity of dosing chlorine at designed speed in hour,

N_{ac} is the quantity of actual chlorine dosed into raw water at unit dosing speed, it can be calculated from equation 10.

$$N_{ac} = \frac{N_{rw}}{N_{clfr}} \quad (10)$$

Where, N_{clfr} is chlorine flow rate injected by chlorinator, it can be determined from equation 11.

$$N_{clfr} = \frac{N_{rw}(sec) \times Dose}{1000} \quad (11)$$

3.2.3 Quality Rate (QR)

Quality Rate is expressed the net quality water transmitted and distributed to customers at the finale of water treatment process. Quality Rate (QR) can be defined by equation 12.

$$QR = 1 - (\%_{lw} + \frac{\lambda_{cl,eq}(t_r + t_{st}) \times N_{rw}(min)}{N_{rw}(year)}) \quad (12)$$

Where, $\%_{lw}$ is percentage of daily loss water from water treatment process.

Thus, A, PE and QR are put to find OEE from equation 13.

$$OEE = A \times PE \times QR \quad (13)$$

3.3 Net Equipment Effectiveness (NEE)

NEE is a characteristic number for being called net entire equipment/plant effectiveness. NEE was developed following the OEE (overall or gross entire equipment effectiveness). NEE effectiveness affects the quality water production. NEE is defined by equation 14[19,20].

$$NEE = Uptime\ ratio \times PE \times QR \quad (14)$$

Where, $Uptime\ ratio$ is the quantity of raw water multiplied by operating time and then divided by average sound product. It can be calculated by equation 15.

$$Uptime\ Ratio\ (Year) = \frac{ASP}{N_{rw}(year) \times t_{ot}} \quad (15)$$

Where, ASP is average sound product of quality water. It can be calculated from equation 16.

$$ASP = N_{rw}(year) \times QR \quad (16)$$

3.4 Profit Cost (PC)

Profit Cost (PC) is an index to measure the budget that the plant will get back from transmitting and distributing quality water after practicing EPS to chlorinators. PC can be defined by equation 17.

$$PC = (ASP_{after} - ASP_{before}) \times Water\ fee \quad (17)$$

4. Parameter for evaluation

Five chlorinators in each couple phase 1&2 and 3&4 at MHS are connectedly grouped as parallel form. Two-fifth operate in 24 hours, when one fails, another will automatically operate instead. Failure rate and parameters of each chlorinator for OEE, NEE and PC evaluations are used in this study shown in Table 2. Practicing EPS, it can reduce 68% of PM time, 90% of failure rate, 41% of repair time and 50% of daily lost water [21].

Table 2. Parameter required to find the improvement from practicing EPS

No.	Parameter	Phase1&2	Phase3&4	Unit	No.	Parameter	Phase1&2	Phase3&4	Unit
1.	$\lambda_{cl,1}$	1	3	Failure/yr	7.	N_{rw}	8	8.8	Sq.m./sec
2.	$\lambda_{cl,2}$	5	7	Failure/yr	8.	Dose	5.5	5.8	-
3.	$\lambda_{cl,3}$	3	2	Failure/yr	9.	v_{mds}	600	600	Kg/hr
4.	$\lambda_{cl,4}$	3	9	Failure/yr	10.	$\%_{lw}$	4.2	4.8	-
5.	$\lambda_{cl,5}$	3	6	Failure/yr	11.	$Water\ fee$	12	12	Baht/Sq.m.
6.	t_{st}	1	1	min.					

5. Evaluation approach and result

In this section, 17 steps and formulas to evaluate the result of OEE, NEE and PC before and after practicing TPM in couple phase 1&2 and 3&4 at MHS are shown in Table 3.

Table 3. 17 steps of OEE, NEE and PC evaluations

No.	Detail	Formula	Phase1&2 Before	Phase1&2 After	Phase3&4 Before	Phase3&4 After	Unit
Availability (A)							
1	t_{pdt}	$t_{pdt} = t_{pm} + (\lambda_{cl,eq} \times t_{st})$	1444.00	460.80	1444.00	460.80	min
2	t_{udt}	$t_{udt} = \lambda_{cl,eq} \times (t_r + t_{st})$	109.55	6.48	192.19	11.37	min
3	t_{lt}	$t_{lt} = 525600 - (t_{pm} + t_{st})$	524156.00	525135.20	524156.00	525135.20	min
4.	t_{ot}	$t_{ot} = t_{lt} + t_{udt}$	524046.45	525128.72	523963.81	525123.83	min
5.	A	$A = \frac{t_{ot}}{t_{lt}} \times 100\%$	99.98	100.00	99.96	100.00	%
Performance Effectiveness (PE)							
6	t_{act}	$t_{act} = \frac{t_{ot}}{N_{rw}}$	2.07	2.08	1.88	1.89	Ms.
7	N_{clfr}	$N_{clfr} = \frac{N_{rw} \times Dose}{1000}$	1387.58	1387.58	1609.59	1609.59	kg/yr
8	N_{ac}	$N_{ac} = \frac{N_{rw}}{N_{clfr}}$	181.82	181.82	172.41	172.41	Sq.m./kg
9	N_c	$N_c = N_{ac} \times v_{mds}(hr)$	955.63	955.63	906.20	906.20	Tg/yr
10	t_{ict}	$t_{ict} = \frac{t_{ot}}{N_c}$	0.548	0.549	0.578	0.579	ms
11	PE	$PE = \frac{t_{ict} \times N_{rw} \times 100\%}{t_{ot}}$	26.40	26.40	30.62	30.62	%
Quality Rate (QR)							
12	QR	$QR = 1 - (\%_{lw} + \frac{\lambda_{cl,eq}(t_r + t_{st}) \times N_{rw}(min)}{N_{rw}(year)})$	93.98	97.45	93.66	97.22	%
Overall Equipment Effectiveness (OEE)							
13	OEE	$OEE = A \times PE \times QR$	24.81	25.73	28.67	29.77	%
Net Equipment Effectiveness (NEE)							
14	ASP	$ASP = N_{rw}(year) \times QR$	237.09	245.85	259.99	269.81	Sq.T./yr
15	$Uptime\ ratio$	$Uptime\ Ratio\ (Year) = \frac{ASP}{N_{rw} \times t_{ot}}$	0.94	0.97	0.94	0.97	-
16	NEE	$NEE = Uptime\ ratio \times PE \times QR$	23.32	25.07	26.87	28.95	%
Profit Cost (PC)							
17	PC	$PC = (ASP_{after} - ASP_{before}) \times Water\ fee$	105.04 (3)		118.53 (3.74)		MBaht (MDollar)

After practicing EPS to chlorinators, OEE increased 0.92% and 1.10% for phase 1&2 and phase 3&4, respectively. While NEE increased 1.75% and 2.08% for phase 1&2 and phase 3&4 respectively, they are shown in Fig.4. Moreover, MHS can transmit and distribute quality water to customers increasingly through PC index, 105 million baht (3 million US dollars) per year and 126 million baht (3.74 million US dollars) per year for phase 1&2 and phase 3&4, respectively.

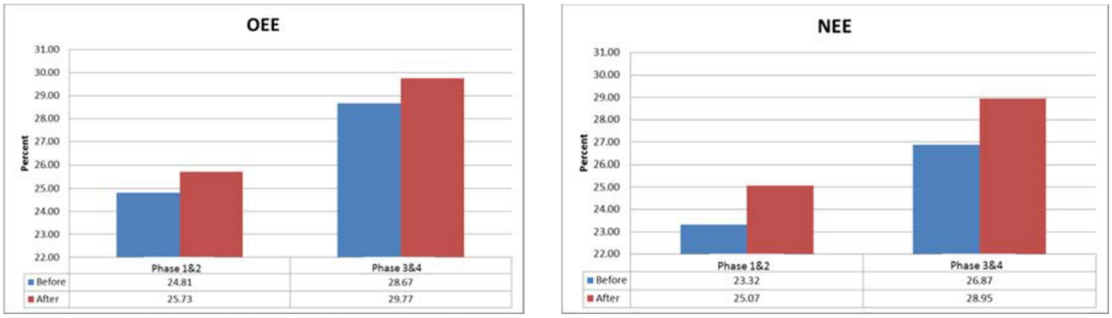

Fig. 4 (a) OEE before and after practicing EPS in each couple phase; (b) NEE before and after practicing EPS in each couple phase.

6. Conclusion

Eight pillars strategy (EPS), one of Total Productive Maintenance (TPM) strategies. It motivates officers to take concept of zero production defects, zero breakdowns and minimal production losses with maximizing equipment effectiveness and stepping up advanced skills to operator and maintenance officer. It eliminated failure rate, increased equipment effectiveness and decreased water loss from water treatment process. In this study, chlorinators in couple phase 1&2 and 3&4 at Mahasawat water treatment plant (MHS) are practiced with EPS as a case study. After practicing EPS to chlorinators, failure rate, PM time, repair time and water loss are more decreasingly. Consequently, chlorinators continuously operate with maximum effectiveness. Operation time, loading time, planned down time and unplanned down time of chlorinators before and after practicing EPS are discussed and considered to evaluate OEE, NEE and Profit Cost (PC) by 17 steps of OEE, NEE and PC evaluations to find the result. As a result, OEE and NEE after practicing EPS are greater than before. Effectively, MHS can get budget back from transmitting and distributing quality water to customers through PC evaluation.

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